Observations of Velocity Fields Under Moderately
Forced Wind Waves

Timothy P. Stanton
Oceanography Department, Code OC/ST
Naval Postgraduate School
Monterey, CA 93943-5000
phone: (831) 656 3144 fax: (831) 656 2712 email: stanton@nps.navy.mil

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LONG TERM GOALS

Long-term goals are to observe and model turbulent transfer of momentum and heat between the atmosphere and ocean in the presence of surface gravity waves. Surface gravity waves play a unique role in the coupling of wind stress into the ocean mixed layer as they gather wind kinetic energy and deliver momentum to the ocean interior through several mechanisms, including micro breaking and full wave breaking. The resulting momentum transfers have both continuous stress components and highly episodic, strong events, which significantly effect vertical distribution of kinetic energy dissipation and turbulent stress in the water column, significantly complicating modeling of this transfer.

OBJECTIVES

The primary scientific objective of this project is to measure the turbulent stresses, shear and kinetic energy dissipation rates in the crest-trough region of wind forced surface gravity waves. Very energetic bursts of turbulent energy injected into this region of the water column by both microbreaking and breaking waves pass momentum and scalar fluxes deeper into the water column though poorly understood processes. It is crucial to measure these properties right up to the wave surface as micro-breaking and gentle spilling breaking events produce disturbances in the water column that change rapidly with distance from the wave surface, and are suspected to generate coherent rotational flows immediately below the surface. Separating out small turbulent signatures from the large amplitude, mostly irrotational flow under ocean waves presents a significant observational challenge. Consequently this study is focused on moderately forced local wind waves, with 10m height winds ranging from 4-10ms^{-1} in ocean environments with low swell climates. Detailed near-surface observations over this range of wind forcing, which spans the transition into wave breaking, will be used to evaluate the role of competing momentum transfer processes in order to formulate improved parameterizations of wind stress transfer into the ocean mixed layer.

APPROACH

While many of the hypotheses for stress transfer under wind waves have been developed from controlled laboratory experiments, the approach taken here is to make direct, noninvasive measurements of the velocity structure under oceanic wind waves without the restrictions imposed by laboratory tanks. Field observations of sub-wave velocity profiles, 2D wave slope and local wave

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breaking have been made over differing wind and wave conditions at sites with minimal swell, to measure the response of the near-surface ocean to the wind forcing. In laboratory tank experiments phase averaging techniques, where nearly identical surface waves are propagated through the tank, allow turbulent motions to be separated from wave motions by ensemble averaging of the flow fields. Since this important analysis technique is not available in field observations under truly random wave fields, other techniques are being developed to identify turbulent momentum fluxes below the waves.

A unique high resolution Bistatic Coherent Doppler Velocity Profiler (BCDVP) developed in my research group at NPS (Stanton 1996, 2001, 2003) has been used during the CBLAST experiment to measure 1.5 cm-resolution profiles of three component velocity vectors and backscatter levels over a 1.5m vertical span immediately below the water surface under wind waves. The bistatic geometry provides a small sample volume, determined by the short acoustic pulse length and narrow transmitter beamwidth, to determine over-resolved 3 component velocity vectors and backscatter level at each range bin through the water column. This small sample volume is critical when sampling close to the highly curved wave surface (and resulting velocity field) immediately below wind waves. The continuous, dense profile of velocity vectors have allow Reynolds stresses to be estimated through the water column in a surface-following coordinate system.

WORK COMPLETED

Delays in fabrication of the MV tower delayed the primary field work into a six week period in July and August 2003. High swell conditions during July and August prevented the WHOI group's deployment of a sub-surface structure that supported the sub-surface oceanographic instruments, so this limited deployment of the near-surface instrument systems to a five day short – fetch observation. Instruments on this frame included the "wide base" BCDV velocity profiler constructed for this experiment, a five element short-base wave slope array, a surface imaging system and a horizontal ADCP that resolved near-surface coherent velocity structures. In addition, a 5 beam BADCP was deployed for 4 weeks 20m from the ASIT tower near Al Pludemann's fan-beam ADCP measurements providing a short opportunity to look at vertical velocity structures associated with Langmuir cell formation at the CBLAST site. It is planned to extend deployment of this instrument through the 03/04 winter.

RESULTS

The five day short fetch deployment of the instrument frame shown in Figure 1 has provided a rich data set to study the velocity field under wind waves with onshore winds between 2 to 10 ms^{-1}. Wind forcing frequently changed abruptly during this period allowing the wave field and

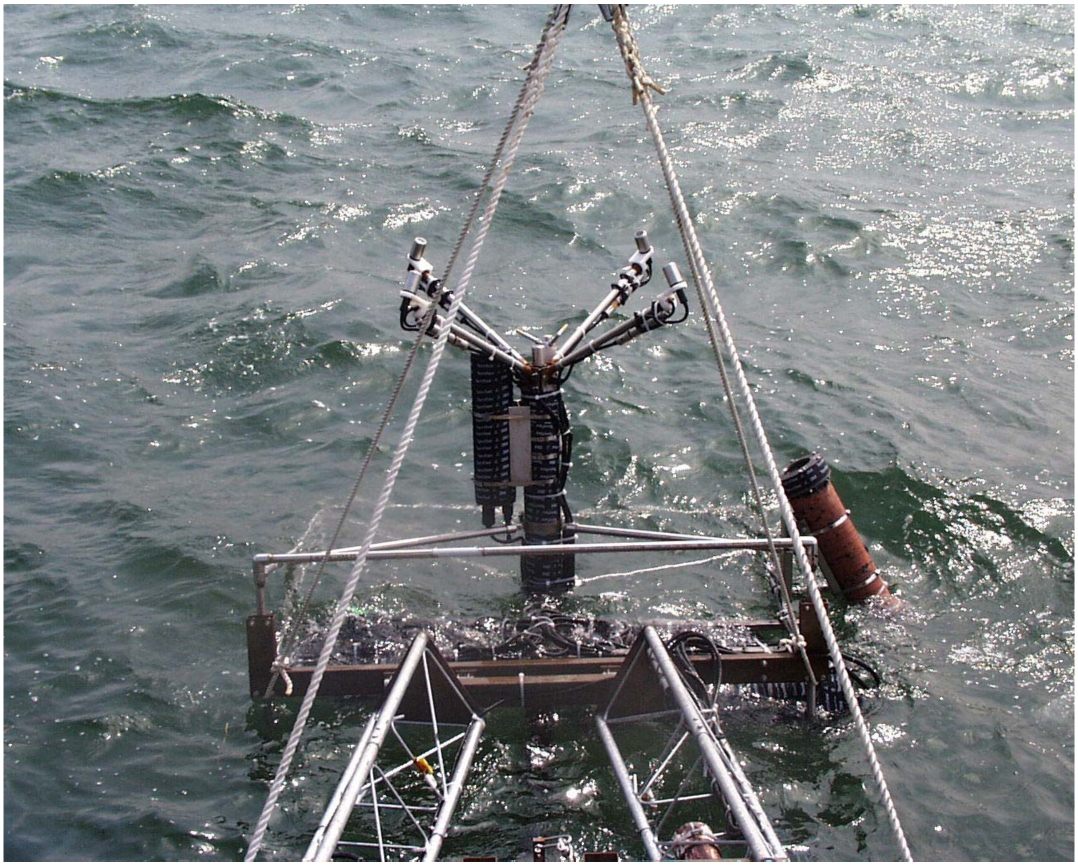

Figure 1. The BCDV velocity profiling instrument and surface imaging system being deployed during CBLAST. The instrument frame tracked tidal excursions, keeping the top of the BCDV 2m below the mean surface elevation.

turbulence levels to be determined outside of saturated conditions. Preliminary analysis of this data set is focused on the velocity structures under moderate wave breaking conditions to estimate the vertical Reynolds stresses associated with discrete breaking events. An illustration of the small scale breaking events seen during the observation period can be seen in the 30 second timeseries of acoustic backscatter energy measured by the BCDV, primarily responding to the void fraction of injected air-bubbles, is shown in Figure 2. Bubbles are rapidly injected to a depth approximately equal to the wave amplitude during the passage of a steep wave near t=7 seconds. Subsequently the bubble plume slowly disperses through rising of larger bubbles, while the small bubble population diffuses down through the water column during the rest of the timeseries. A method to map stress, shear and scalar properties into a surface-referenced coordinate system is being used to estimate stress and shear production during these events, and reveal longer-lived coherent structures within the water column. This techniques minimizes the contribution of large irrotational flow components in the estimation of the turbulent stress timeseries $\rho\langle u'w'\rangle(z_{\eta,},t)$ and $\rho\langle v'w'\rangle(z_\eta,t)$, where z_η is the distance down from the wave surface, that are being used to identify stress events associated with incipient and spilling breaking. The η-following reference frame allows Reynolds averages of these stress timeseries to be formed over appropriate averaging times to within1 cm of the surface the surface despite the large vertical excursion of the surface. Near the time of the short timeseries in Figure 2, larger scale Langmuir circulations were seen in the horizontal velocity and backscatter transects that were measured by a horizontal BADCP at 3m depth every 0.25m over a 16m range approximately orientated 45 degrees cross-wind. The link between the near surface breaking events and these larger scale, deeper structures are being studied in the on-going analyses.

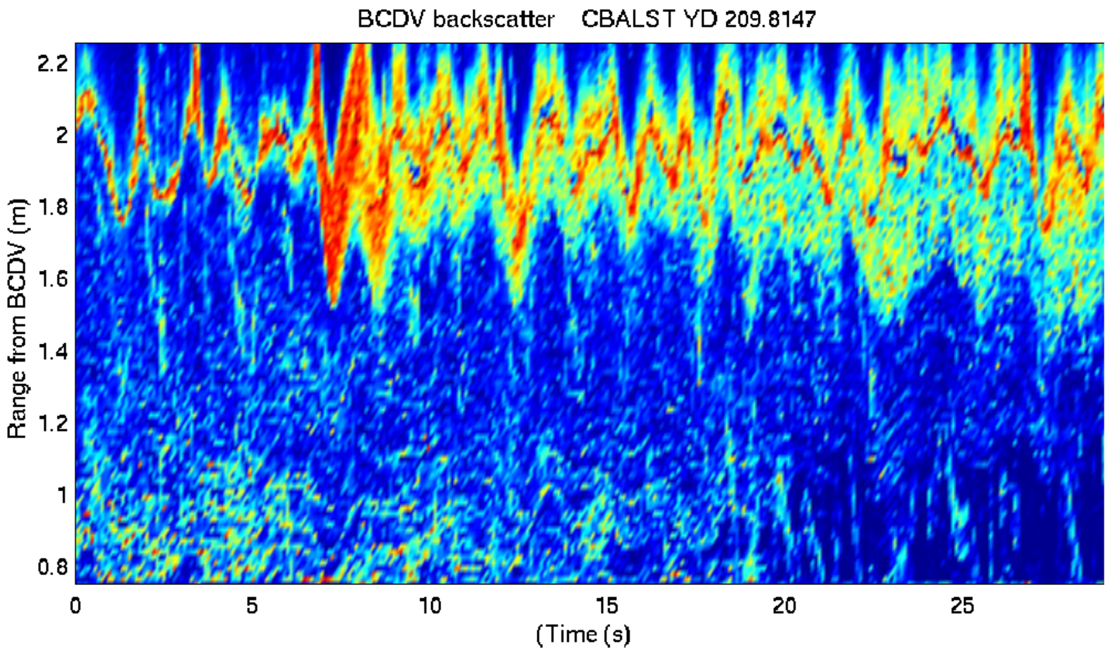

Figure 2. A 30 second profile timeseries of backscatter levels under short period wind waves shows bubbles injected during a wave breaking event at t=7 seconds, with a slow diffusion of the air bubble plume through the rest of the timeseries.

IMPACTS/APPLICATIONS

Improved observations of the processes responsible for stress transfer into the ocean wind momentum transfer into the ocean have broad application to air-sea interaction and gas exchange studies. There is a clear need for improved drag coefficient parameterizations, in both atmospheric and oceanic models, particularly under light to moderate winds in very high resolution littoral modeling efforts including COAMPS.

RELATED PROJECTS

This research is closely coordinated with other CBLAST investigators including Jim Edson (atmospheric boundary layer), Al Pludemann (Langmuir circulations), Jean Terray and John Towbridge (mixed layer velocities).

TRANSITIONS

A technology transfer is underway to commercialize the BCDV profiler to provide wider access to this technology.

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